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RESEARCH MEMORANDUM

for the

Air Materiel Command, U. S. Air Force

SPIN INVESTIGATION OF A $\frac{1}{29}$-SCALE MODEL OF THE REPUBLIC XF-91 AIRPLANE WITH A CONVENTIONAL TAIL INSTALLED

By

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SPIN INVESTIGATION OF A $\frac{1}{29}$-SCALE MODEL OF THE REPUBLIC XF-91 AIRPLANE WITH A CONVENTIONAL TAIL INSTALLED

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SUMMARY

An investigation has been conducted in the Langley 20-foot free-spinning tunnel of a $\frac{1}{29}$-scale model of the Republic XF-91 airplane with a conventional-tail arrangement installed. Previously, tests were made on the model with a vee tail installed. The erect spin and recovery characteristics of the model were determined for the normal loading with the wing installed at various amounts of incidence. The spin investigation also included inverted-spin tests, spin-recovery-parachute tests, tests with the center of gravity moved rearward, and tests with external fuel tanks added to the model. In addition, several tail modifications were tested on the model in an attempt to improve the model's spin-recovery characteristics.

The results indicate that any fully developed spin obtained on the airplane with the conventional tail installed will be satisfactorily terminated if rudder reversal is accompanied by moving the ailerons with the spin (stick right in a right spin). Decreasing the wing incidence from 6° to -2° should have a beneficial effect on the recovery characteristics of the airplane. Recovery characteristics by normal use of controls (full rudder reversal followed by moving the elevators down) will be satisfactory if the wing incidence of the airplane is -2°. Installation of external fuel tanks (with or without fuel) will have a somewhat adverse effect on the recovery characteristics of the airplane, but if the recovery technique includes movement of the ailerons to full with the spin, the spin rotation will be terminated rapidly. Varying the position of the center of gravity within the limits indicated to be possible on the airplane should not affect

the recovery characteristics. Recoveries from inverted spins should be terminated satisfactorily by full reversal of the rudder. The model test results show that either moving the tail surfaces rearward 17.4 inches (full scale) and adding ventral-fin area, or approximately doubling the rudder chord would insure satisfactory spin recovery for the airplane for any condition without the aid of ailerons. The model test results indicated that a $9\frac{2}{3}$-foot-diameter conventional-type parachute (drag coefficient approx. 0.70) attached to the tail should be effective as an emergency spin-recovery device during demonstration spins.

INTRODUCTION

In accordance with a request by the Air Materiel Command, U. S. Air Force, an additional investigation was performed in the Langley 20-foot free-spinning tunnel to determine the spin and recovery characteristics of a $\frac{1}{29}$-scale model of the Republic XF-91 airplane with a conventional-tail installation. A previous spin investigation has been conducted in the spin tunnel on the XF-91 model equipped with a vee tail. (See reference 1.)

For the current tests, the erect and inverted spin characteristics of the model were investigated for the normal loading, and the effect of varying the wing incidence from 6° to -2° was determined. In addition, tests were performed with external fuel tanks installed on the model, and the effect of moving the center of gravity rearward was also determined. Various tail modifications were investigated in an attempt to improve the model's spin-recovery characteristics, and tests were performed to determine the minimum-size tail parachute required for emergency spin recovery.

SYMBOLS

b	wing span, feet
S	wing area, square feet
$\bar{c}$	mean aerodynamic chord, feet

$x/\bar{c}$ ratio of distance of center of gravity rearward of leading edge of mean aerodynamic chord to mean aerodynamic chord

$z/\bar{c}$ ratio of distance between center of gravity and thrust line to mean aerodynamic chord (positive when center of gravity is below thrust line)

m mass of airplane, slugs

I_X, I_Y, I_Z moments of inertia about X, Y, and Z body axes, respectively, slug-ft^2

$\frac{I_X - I_Y}{mb^2}$ inertia yawing-moment parameter

$\frac{I_Y - I_Z}{mb^2}$ inertia rolling-moment parameter

$\frac{I_Z - I_X}{mb^2}$ inertia pitching-moment parameter

ρ air density, slugs per cubic foot

μ relative density of airplane $(m/\rho Sb)$

α angle between thrust line and vertical (approx. equal to absolute value of angle of attack at plane of symmetry), degrees

ϕ angle between span axis and horizontal, degrees

V full-scale true rate of descent, feet per second

Ω full-scale angular velocity about spin axis, rps

σ helix angle; angle between flight path and vertical, degrees (For this model, the average absolute value of the helix angle was approx. 4°.)

β approximate angle of sideslip at center of gravity, degrees (Sideslip is inward when inner wing is down by an amount greater than the helix angle.)

APPARATUS AND METHODS

Model

The $\frac{1}{29}$-scale model of the Republic XF-91 airplane used for the investigation reported in reference 1 was used in the present investigation except that the vee tail was replaced with a conventional-tail arrangement. The dimensional characteristics of the XF-91 airplane as represented by the model are presented in table I. A three-view drawing of the model as tested with the conventional tail installed is shown in figure 1, and a sketch of the external fuel-tank installation is shown in figure 2. Photographs of the model in the clean condition and with the external fuel tanks installed are shown in figure 3. Sketches of various tail modifications tested on the model are shown in figure 4 and a photograph showing the model spinning in the tunnel is presented in figure 5.

The model was ballasted with lead weights to obtain dynamic similarity to the airplane at an altitude of 15,000 feet ($\rho = 0.001496$ slug/cu ft). A remote-control mechanism was installed in the model to activate the controls for recovery tests. Sufficient moments were exerted on the control surfaces during recovery tests to reverse the controls fully and rapidly.

The model parachutes used were of the flat circular type, made of silk, and had a drag coefficient of approximately 0.7 based upon the surface area.

The tail-damping power factor was computed by the method described in reference 2.

Wind Tunnel and Testing Technique

The tests were performed in the Langley 20-foot free-spinning tunnel. The testing technique applied and methods for determining the spin data were essentially the same as those reported in reference 1.

As has been explained in reference 1, tests were performed to determine the spin and recovery characteristics of the model for the normal-spinning-control configuration (elevator full up, ailerons neutral, and rudder full with the spin) and for various other aileron-elevator combinations including neutral and maximum settings of the controls for various model loadings and configurations. Recovery was generally attempted by rapid reversal of the rudder from full with to full against the spin. For some of the tests, recovery was also attempted by reversing the ailerons from their original against-the-spin setting (right aileron down and left aileron up in a right spin) to their maximum deflection in the opposite direction (full with the spin; stick right in a right spin). Tests were also performed to evaluate the possible adverse effects on recovery of small deviations from the normal-control configuration for spinning. For these tests, the elevator is set at two-thirds of its full-up deflection and the ailerons are set at one-third of full deflection in the direction conducive to slower recoveries (against the spin for the XF-91 model for all loadings tested). Recovery from this spin is attempted by rapidly reversing the rudder alone from full with to two-thirds against the spin or by moving the rudder to two-thirds against the spin in conjunction with elevator reversal. If the model recovers within $2\frac{1}{4}$ turns from this spin, the recovery characteristics of the model are considered satisfactory and taken to indicate that recoveries from spins on the full-scale airplane by normal manipulation of the controls (i.e., reversal of the rudder followed approx. one-half turn later by elevator reversal; ailerons placed at neutral) will be satisfactory. This criterion has been based on full-scale airplane spin-recovery data that are available for comparison with corresponding model results.

The testing technique for determining the optimum size of and the towline length for spin-recovery parachutes is described in detail in reference 3. In brief, the model in the original configuration was launched into the tunnel with the rudder set full with the spin. For recovery attempts, the rudder was held with the spin. The parachute pack and towline were attached to the model in such a manner as to have no effect on the steady spin before being opened. For the tail parachute tests, the parachute pack and towline were attached to the model at the rear of the fuselage just above and slightly forward of the rocket-motor exit. The parachute was packed below the horizontal tail at the juncture of the fin and fuselage on the outboard side of the fuselage (left side in a right spin). The parachute was opened for the recovery attempt by actuating the remote-control mechanism. (See reference 3.)

The precision of the test results and the limits of accuracy of the mass characteristics of the model for the present tests are similar to those presented in reference 1.

TEST CONDITIONS

Tests were performed for the model conditions listed in table II. For all tests, the flaps were neutral, the landing gear was retracted, and the cockpit was closed. Mass characteristics and mass parameters for the normal-loading condition and other loading conditions possible on the airplane, as well as for the loadings tested on the model, are listed in table III. The mass-distribution parameters for the loadings possible on the XF-91 airplane and for the loadings tested on the model are plotted in figure 6. As discussed in reference 4, figure 6 can be used in predicting the relative effectiveness of the controls on the recovery characteristics of the model.

The normal-maximum-control deflections (measured perpendicular to hinge line) used in the tests were as follows:

Rudder, deg	25 right, 25 left
Elevator, deg	30 up, 15 down
Ailerons, deg	20 up, 18 down

RESULTS AND DISCUSSION

The results of the model tests are presented in charts 1 to 7 and in tables IV and V in terms of the full-scale airplane values at a test altitude of 15,000 feet. Because of some inherent asymmetry in the model construction, recoveries from the spins to the right were somewhat slower than the recoveries from the corresponding left spins for a few control configurations. Accordingly, the greater portion of the tests was conducted for the model spinning to the right, and the data presented in the charts for the right spins are considered slightly conservative. A comparison of the results for both the right and the left spins is also presented for some of the conditions tested.

Normal Loading

<u>Model results</u>.- The results of the spin tests for the normal loading are presented in charts 1, 2, and 3 for wing incidences of 6°, 0°, and -2°, respectively. When the wing was installed on the model at an incidence of 6°, the model spun steeply at the normal-spin-control configuration (ailerons neutral, elevator full up, and rudder full with the spin) for both the right and the left spins and recovered rapidly when the rudder alone was reversed. With the ailerons at neutral and the elevator set at neutral or down, recoveries from the right spins were retarded, whereas recoveries from the left spins were not affected by elevator position. Ailerons set full against the spin generally flattened both the right and the left spins and retarded recoveries; whereas when the ailerons were set full with the spin, the model did not spin but entered either a steep tight spiral or a steep aileron roll.

In order to determine the sensitivity of the model to small variations in elevator and aileron setting from the normal-spin-control configuration and to small variations in rudder deflection when the wing was installed at an incidence of 6° on the model, the model was spun with the ailerons placed one-third against the spin (in the direction conducive to slower recoveries) and with the elevator set at two-thirds of its full-up setting. Recovery was attempted from this spin by reversing the rudder to only two-thirds of its full deflection against the spin. As has been explained previously, satisfactory recovery from this spin is taken as an indication that the recovery characteristics of the airplane will be satisfactory when normal spin-recovery technique (full rudder reversal followed one-half turn later by moving the elevator down) is employed for the normal-spin-control configuration. Results presented in chart 1 show that either the model did not recover from this spin or recovered very slowly. The results also show that when the elevator was set two-thirds full up, the model recovered when the ailerons were neutral; whereas when the ailerons were displaced against the spin only a very slight amount, unsatisfactory recoveries were obtained. The test results thus indicate that the recovery characteristics of the full-scale airplane may be critically dependent upon the position of the ailerons when the airplane is spun with 6° wing incidence, and that placing the ailerons only slightly against the spin may seriously retard recoveries. The data presented in charts 2 and 3 indicate that the sensitivity to aileron settings against the spin will be decreased and also that the recovery characteristics in general will be improved as the wing incidence is decreased from 6° to -2°. In fact, the results show that when the wing was placed at an incidence of -2° on the model, satisfactory recoveries were obtained even when the ailerons were deflected as much as one-third against the spin.

In order to improve the recovery characteristics of the model from the spins obtained with ailerons set against the spin, recoveries were attempted by simultaneously reversing both the rudder and elevator, by simultaneously reversing the rudder and moving the ailerons from against to full with the spin, and by moving only the ailerons to with the spin, the rudder remaining full with the spin. The results of these tests, presented in chart 4, show that reversal of the elevator in conjunction with rudder reversal had no beneficial effect on the model's recovery characteristics; whereas moving the ailerons from against to full with the spin (alone or in combination with rudder reversal) effectively terminated the spin, even when the wing incidence was 6°. These results thus indicate that the ailerons were an extremely effective control in producing recovery from a spin; whereas the elevator provided little beneficial effect.

Full-scale interpretation of model results.- Inasmuch as the wing incidence of the XF-91 airplane is variable in flight from 6°

to -2°, it is possible that the airplane may be spun with 6° wing incidence. As has just been discussed, the model test results indicate that with 6° incidence in the wing, the airplane may not recover satisfactorily from spins by normal manipulation of the controls for recovery (i.e., rudder reversal followed by elevator reversal, ailerons maintained at neutral). It appears, however, that satisfactory recoveries from spins of the airplane can be obtained by deviating somewhat from the normal-spin-recovery technique. For spins that are entered with the ailerons very nearly at neutral, if the rudder is reversed briskly from full with the spin to full against the spin while the stick is permitted to float laterally, the variation in angle of attack along the wing during a spin will probably be such as to cause the ailerons to float with the spin, and the airplane should recover satisfactorily. As the airplane begins to nose down during recovery, the stick should be moved forward. Care should be exercised to avoid moving the stick forward too soon since premature reversal of the elevators may blanket out part of the rudder and cause it to become less effective in bringing about recovery. The model test results indicate further that satisfactory recovery from any spin, regardless of the initial setting of the ailerons, can be obtained by moving the stick laterally to full with the spin as the rudder is reversed fully and rapidly for recovery. Recovery attempted in this manner will result in a steep aileron roll and will require neutralization of the ailerons after recovery from the spin to terminate the roll. Inasmuch as it appears that special recovery technique may be required to insure satisfactory recovery from spins on the full-scale XF-91 airplane, the recovery characteristics of the airplane are considered marginal.

In the past it has not been a general policy to recommend movement of the ailerons to with the spin to effect recovery, because movement of an additional control for recovery may cause a pilot to be somewhat confused, and also because spin-tunnel tests have indicated in the past that a model is generally slow to respond to the aileron movement. For airplanes that have a very great portion of their weight distributed along the fuselage relative to the weight in the wings, as has the XF-91, it might be expected that, because of inertia effects, the response of the airplane to aileron movement during spins might be fast and even faster than its response to movement of the rudder or elevator. Thus it would appear that rudder and ailerons instead of rudder and elevator might be the predominant controls in effecting recovery from spins for airplanes that are loaded very heavily along the fuselage. This has been borne out by the results of the XF-91 model spin tests.

When the XF-91 airplane is to be spun intentionally, the model test results indicate that the wing should first be placed at an incidence of -2° to minimize the unfavorable effect of placing the ailerons against the spin. The model results further indicate that with the wing at -2° incidence, the airplane will recover satisfactorily from fully developed spins even by normal usage of the controls. It should be noted that if a spin is entered with the wing set at 6° incidence that changing the wing incidence in flight to -2°, although favorable, may not be a means for satisfactorily terminating the spin by normal movement of the controls because of the time regained for the wing incidence and the air flow about the airplane to change.

Effect of Wing Tanks

Tests were performed with the external fuel tanks installed on the model for the tank-empty condition and for the condition with fuel added to the tanks to simulate the airplane loading after take-off and climb to 50 feet. The results of these tests are presented in chart 5 and show that the addition of the empty or partially full external wing tanks had a somewhat adverse effect on the recovery characteristics of the model, but that the favorable effect of placing the ailerons full with the spin still persisted. The test results presented in chart 4 show that recoveries from spins could still be effected by moving the ailerons to full with the spin. If a spin is inadvertently encountered when the airplane is being flown with the external wing tanks installed, and if recovery does not appear imminent after movement of controls for recovery, the wing tanks should be jettisoned.

Effect of Varying Center-of-Gravity Position

The results of tests presented in chart 6 show the effects of moving the center of gravity rearward from normal. Moving the center of gravity rearward from its normal position at 16 percent of the mean aerodynamic chord to approximately 20 percent of the mean aerodynamic chord (indicated to be the most rearward position of the center of gravity possible on the airplane) did not appreciably affect the spin and recovery characteristics of the model. Brief tests made on the model loaded to simulate the loading tested with the vee-tail configuration, as reported in reference 1 (center of gravity moved back to 24 percent of the mean aerodynamic chord and radius of gyration about Y-axis increased relative to radius of gyration about X-axis) show that the spins generally became more oscillatory in roll and yaw, and that the recovery characteristics of the model were generally improved. Inasmuch as the model tended to resist spinning when the center of gravity was at 24 percent of the mean aerodynamic chord, additional tests were conducted with the center of gravity moved farther rearward to 31 percent of the mean aerodynamic chord. With this position of the center of gravity no spins were obtained. These results are in general agreement with results obtained with other spin models loaded heavily along the fuselage in that rearward movements in the center of gravity resulted in a change in the nature of the spin so that the spins became increasingly oscillatory in yaw and roll as the center of gravity was moved rearward. (See reference 5.) Further rearward movements of the center of gravity caused the spin of the XF-91 model to cease entirely.

Inverted Spins

The results of the inverted-spin tests of the model in the design-gross-weight loading are presented in chart 7. The order used for presenting the data for inverted spins is different from that used for erect spins. For inverted spins, controls crossed for the established spin (right rudder pedal forward and stick to the pilot's left for a spin to the pilot's right) is presented to the right of the chart and stick back is presented at the bottom. When the controls are crossed in the established spin, the ailerons aid the rolling motion; when the controls are together, the ailerons oppose the rolling motion. The angle of wing tilt ϕ in the chart is given as up or down relative to the ground.

The model did not spin when the controls were crossed, but spins were obtained when the ailerons were neutral and when the controls were together. The model results indicate that the inverted spin can be satisfactorily terminated on the full-scale airplane by fully reversing the rudder.

These results are different from those that might have been expected based on the information that has been published on inverted spins. Reference 6 states that controls together tend to prevent the inverted spin and that crossing controls retards recovery from the inverted spins. Also, spin-model test results have indicated that merely neutralizing all controls generally terminates the inverted spin rapidly. These differences are explained on the fact that the XF-91 is loaded very heavily along the fuselage, and also on the fact that the relative effectiveness of the vertical tail at spinning attitudes is approximately the same for both the erect and inverted spins for the XF-91. Both these factors combined tend to make both the recovery characteristics and the spinning and nonspinning regions similar for both the erect and inverted spins. (Compare charts 2 and 7.) The models for which the study presented in reference 6 was made were loaded more equally along fuselage and wing, and the horizontal tail was generally so positioned that the vertical tail was considerably more effective for the inverted spins than for the erect spins. The combination of these factors apparently tends to make the results for the XF-91 model for inverted spins somewhat different from those indicated in reference 6.

Spin-Recovery Parachutes

Results of the spin-recovery-parachute tests are presented in table IV. A tail parachute $9\frac{2}{3}$ feet in diameter (full scale) with a towline length equivalent to the wing span appears to be necessary for satisfactory recovery from spins by parachute action alone. As previously mentioned, the parachute was attached above the jet exit at the rear of the fuselage, and was of the flat-type variety having a drag coefficient of approximately 0.7. If a parachute with a different drag coefficient is used, a corresponding adjustment will be required in parachute size. Reference 7 indicates that a flat-type parachute is unstable and may seriously affect the stability of the airplane in normal flight when the parachute is opened to test its operation. It may be desirable, therefore, to use a stable parachute instead of a conventional parachute as an emergency spin-recovery device. Computations based on the results presented in reference 7 show that a stable hemispherical parachute 7.7 feet in diameter (projected diam.) and having a porosity of 400 and a drag coefficient of 1.1 would provide about the same amount of damping in a spin as a $9\frac{2}{3}$-foot diameter flat-type parachute.

Tail Modifications

In order to obtain satisfactory recovery by normal use of controls from a fully developed spin for any condition possible on the airplane, it appears that some modification of the design will be required. Accordingly, several tail modifications were tested on the model. The modifications tested are tabulated in table V and are classified as effective or ineffective depending on whether they did or did not satisfactorily improve the model's spin-recovery characteristics. The test data indicate that in order to improve effectively the spin-recovery characteristics of the model, it was necessary either to move the tail surfaces rearward a minimum of 17.4 inches (full scale) and add ventral-fin area (modification number 8 in fig. 4), or to approximately double the chord of the rudder (modification number 5 in fig. 4).

Landing Condition

The landing condition was not investigated on this model inasmuch as current Air Force specifications require this type of airplane to demonstrate satisfactory recoveries in the landing condition from only one-turn spins. At the end of one turn the airplane will probably still be in an incipient spin from which recoveries are more readily obtained than from fully developed spins.

An analysis of full-scale and model tests to determine the effects of landing flaps and landing gear indicates that, although the XF-91 will probably recover satisfactorily from an incipient spin in the landing condition, recoveries from fully developed spins may be unsatisfactory. Therefore, in order to avoid entering a fully developed spin, it is recommended that the landing flaps be neutralized and recovery be attempted immediately upon inadvertently entering a spin in the landing condition.

Comparison of Vee- and Conventional-Tail Results

The data presented in reference 1 for the vee-tail configuration are limited to a wing incidence of 0° and a loading having the center of gravity positioned at about 26 percent of the mean aerodynamic chord. Comparison of the data presented in reference 1 with the data presented in chart 6 for the conventional-tail installation indicates that with the center of gravity in the neighborhood of the 1/4 mean aerodynamic chord and a wing incidence of 0°, the spin-recovery characteristics of the model with either the conventional- or vee-tail installations were good. In addition, unpresented test results show that, with the vee tail installed on the model, slow recoveries could be obtained if ailerons were slightly against the spin when the wing incidence was 6° and the center-of-gravity position was at 16 percent of the mean aerodynamic chord (corresponding to loading number 1 in table III). These results are similar to the results presented in chart 1 for the model with the conventional-tail installation, although it should be pointed out that the vee-tail tests were conducted with a rudder deflection of only ±8°; whereas the conventional tail was tested with a ±25° rudder throw. It appears that for the XF-91 design the loading dictates the results obtained to a greater extent than does the tail so that recovery characteristics with either the conventional tail or the vee tail installed will generally be similar.

CONCLUSIONS

Based on results of a spin investigation of a $\frac{1}{29}$-scale model of the Republic XF-91 airplane, the following conclusions regarding the spin and recovery characteristics of the airplane at a spin altitude of 15,000 feet are made:

1. The recovery characteristics of the airplane in the design gross weight and with 6° incidence in the wing will be marginal from fully developed spins. Recovery should be attempted by simultaneous movement of the ailerons to full with the spin and full reversal of the rudder. As the airplane begins to nose down during recovery, the stick should be moved forward.

2. Decreasing the wing incidence will have a beneficial effect on the recovery characteristics. If a spin is entered with the wing of -2° incidence, the recovery characteristics of the airplane will be satisfactory and it will not be necessary to use the ailerons to recover from spins.

3. The external wing fuel tanks (with or without fuel installed) will affect the spin-recovery characteristics somewhat adversely. If recovery does not appear imminent after a recovery attempt is made, the tanks should be jettisoned.

4. Moving the center of gravity rearward from normal within the range indicated to be possible on the airplane will not affect the spin-recovery characteristics. Further rearward movements of the center of gravity will cause the spins to become more oscillatory in roll and yaw and will have a beneficial effect on the recovery characteristics.

5. Satisfactory recovery from inverted spins will be obtained by full reversal of the rudder.

6. A $9\frac{2}{3}$-foot flat-type parachute (Drag coefficient = 0.70) or a stable hemispherical parachute 7.7 feet in diameter (Drag coefficient = 1.1) attached to the tail will be effective for emergency recovery from demonstration spins.

7. In order to enable the airplane to recover satisfactorily from any fully developed spin by normal usage of the controls (i.e., rudder reversal followed approx. one-half turn later by reversal of the elevator, ailerons maintained at neutral), it will be necessary to modify the tail of the airplane. Either doubling the size of the rudder chord, or moving the tail surfaces rearward a minimum of 17.4 inches (full scale) and adding ventral-fin area will effectively

improve the recovery characteristics of the airplane so that recovery will be effected without the aid of the ailerons.

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TABLE I.- DIMENSIONAL CHARACTERISTICS OF XF-91 AIRPLANE WITH CONVENTIONAL TAIL AS SIMULATED FOR MODEL TESTS

Length over all, ft	43.33
Wing:	
Span, ft	31.34
Area, sq ft	322.2
Section, root	Republic R-4, 40-1710-1.0
Section, tip	Republic R-4, 40-10-1.0
Incidence, deg	Variable from -2 to 6
Wing twist	0
Aspect ratio	3.05
Taper ratio	0.62
Sweepback of 50-percent-chord line, deg	40
Dihedral of wing, deg	-5
Mean aerodynamic chord, in.	127.08
Leading edge $\bar{c}$ aft of leading-edge root chord, in.	69.04
Ailerons:	
Total area, sq ft	45.6
Span, percent b/2	40.9
Horizontal tail:	
Total area, sq ft	69.61
Elevator area, sq ft	21.1
Distance from normal center of gravity to intersection of elevator hinge lines at the plane of symmetry of model, ft	15.69
Vertical tail:	
Total area, sq ft	48.30
Rudder area, sq ft	9.78
Distance from normal center of gravity to intersection of rudder hinge line and stabilizer chord line, ft	16.97
Tail-damping power factor	450×10^{-6}

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[redacted]

TABLE II.- CONDITIONS TESTED ON MODEL

Type of test	Loading	Variation from normal clean condition	Wing incidence (deg)	Method employed in recovery attempt	Data
Right and left errect spins	Normal	None	6	Rudder reversal	C
Do--------	-----------do-----------	--------do--------	0	--------------do---------------	C
Do--------	-----------do-----------	--------do--------	-2	--------------do---------------	C
Right erect spins	-----------do-----------	--------do--------	6, 0	Simultaneous rudder and elevator reversal; simultaneous rudder and aileron reversal; aileron reversal; rudder reversal	C
Do--------	Condition after take-off and climb to 50 feet	Wing tanks installed	0	Simultaneous rudder and aileron reversal; aileron reversal; rudder reversal	
Do--------	-----------do-----------	--------do--------	0	Rudder reversal	C
Do--------	Normal loading plus empty wing tanks	--------do--------	0	--------------do---------------	
Do--------	Center of gravity at 20-percent $\bar{c}$	None	0	--------------do---------------	C
Do--------	Center of gravity at 24-percent $\bar{c}$	--------do--------	6	--------------do---------------	
Do--------	Center of gravity at 31-percent $\bar{c}$	--------do--------	6	--------------do---------------	
Inverted spins to pilot's right	Normal	--------do--------	0	--------------do---------------	C
Right erect spins	-----------do-----------	--------do--------	6	Tail parachutes	T
Right erect spins	-----------do-----------	Tail modifications	6	Rudder reversal	T

[redacted]

TABLE III.- MASS CHARACTERISTICS AND INERTIA PARAMETERS FOR LOADINGS POSSIBLE ON XF-91 AIRPLANE AND FOR LOADINGS TESTED ON MODEL

[Model values converted to corresponding full-scale values]

Number	Loading condition	Weight (lb)	Relative density, μ		Center-of-gravity position		Moments of inertia			Mass parameters		
			Sea level	15,000	$x/\bar{c}$	$z/\bar{c}$	I_X (slug-ft^2)	I_Y (slug-ft^2)	I_Z (slug-ft^2)	$\frac{I_X - I_Y}{mb^2} \times 10^{-4}$	$\frac{I_Y - I_Z}{mb^2} \times 10^{-4}$	$\frac{I_Z - I_X}{mb^2} \times 10^{-4}$
	Airplane values											
1	Normal gross weight	18,600	24.06	38.2	0.165	0.026	14,783	48,724	60,572	-598	-208	806
2	Condition after take-off and climb to 50 feet (wing tanks installed)	24,532	31.73	50.40	.200	.048	22,148	55,217	71,270	-441	-215	656
3	Normal gross weight plus empty wing tanks	19,601	25.35	40.28	.176	.012	16,084	50,136	62,675	-571	-209	780
4	Most rearward position of center of gravity possible	15,177	19.62	31.13	.204	.002	14,775	43,138	54,898	-614	-253	867
5	Vee-tail loading with nearly all fuel and ammunition expended (reference 1)	14,172	18.33	20.12	.260	.013	15,234	47,108	60,632	-738	-313	1051
	Model values											
1	Normal gross weight	18,615	24.07	38.25	0.160	0.028	15,196	50,613	62,558	-624	-211	833
2	Condition after take-off and climb to 50 feet (wing tanks installed)	24,532	31.73	50.40	.200	.059	23,117	54,723	70,668	-422	-213	636
3	Normal gross weight plus empty wing tanks	19,615	25.36	40.3	.166	.044	16,503	52,736	65,306	-606	-210	816
4	Most rearward position of center of gravity possible	15,169	19.62	31.17	.201	.016	15,043	44,006	56,129	-626	-262	888
5	Center of gravity moved to 24-percent $\bar{c}$ (loading as tested in reference 1)	14,240	18.40	29.20	.240	.002	15,430	47,742	60,395	-741	-290	1031
6	Center of gravity moved to 31-percent $\bar{c}$	15,861	20.51	32.6	.311	.025	15,687	50,583	63,000	-722	-257	979
7	Normal gross weight with tail moved back 49.3 in.	18,834	24.36	38.72	.194	.027	15,779	62,914	75,215	-820	-214	1035
8	Normal gross weight with tail moved back 32.6 in.	18,834	24.36	38.72	.179	.027	15,779	59,699	72,006	-765	-214	979
9	Normal gross weight with tail moved back 17.4 in.	18,834	24.36	38.72	.164	.027	15,779	56,675	68,975	-712	-214	926

TABLE IV.- SPIN-RECOVERY-PARACHUTE TEST DATA OBTAINED

FOR MODEL

[Normal loading; 6° wing incidence; drag coefficient of parachutes $\approx$ 0.70; recovery attempted from spin having ailerons one-third against spin and elevator at two-thirds full up; recovery attempted by parachute action alone, rudder remaining full with the spin; towline length = 31.2 ft (full scale); right erect spins]

Parachute diameter (ft, full scale)	Turns for recovery
8.94	$1\frac{3}{4}$, $2\frac{1}{4}$, $2\frac{1}{2}$, 3, 3
9.67	$1\frac{1}{4}$, $1\frac{3}{4}$, $1\frac{3}{4}$, $1\frac{3}{4}$, $2\frac{1}{4}$
10.88	$1\frac{1}{4}$, $1\frac{3}{4}$, $1\frac{3}{4}$, $1\frac{3}{4}$
12.09	[a]1, 1, $1\frac{1}{2}$, [a]$1\frac{3}{4}$, [a]$1\frac{3}{4}$

[a]Model made about two turns about parachute axis after assuming a vertical attitude before rotation stopped.

[redacted]

TABLE V.- EFFECT OF TAIL MODIFICATIONS ON SPIN AND RECOVERY CHARACTERISTICS OF XF-91 MODEL WITH 6° WING INCIDENCE

Approximate normal loading (adding the modifications caused variations in the normal loading as indicated); landing gear and flaps retracted; cockpit closed; recoveries attempted from and steady-spin data presented for rudder-with spins; recovery by rudder reversal as indicated; model values converted to corresponding full-scale values; right erect spins

Description of modification	Effectiveness of modification	Control settings: Rudder, Initial	Control settings: Rudder, Final	Control settings: Elevator	Control settings: Ailerons	α (deg)	ϕ[a] (deg)	Ω (rps)	V (ft/sec)	Turns for recovery	Loading (See table III.)
Modification 1; rudder span increased	Ineffective	Full right	$\frac{2}{3}$ L	$\frac{2}{3}$ U	$\frac{1}{3}$ A	55	3U	0.27	239	>3, ∞	1
Modification 2; rudder span increased and ventral fin added	Ineffective	Full right	$\frac{2}{3}$ L	$\frac{2}{3}$ U	$\frac{1}{3}$ A	55	3U	.27	239	>3, ∞	1
Modification 3; rudder chord increased $1\frac{1}{2}$ times and rudder span increased	Ineffective	Full right	$\frac{2}{3}$ L	$\frac{2}{3}$ U	$\frac{1}{3}$ A	40 to 65	-----	.26	239	>4	1
Modification 4; tail surfaces moved rearward 32.63 in.	Ineffective	Full right	$\frac{2}{3}$ L	$\frac{2}{3}$ U	$\frac{1}{3}$ A	-----	-----	.26	249	∞	8
Modification 5; rudder chord doubled and rudder span increased	Effective	Full right	$\frac{2}{3}$ L	$\frac{2}{3}$ U	$\frac{1}{3}$ A	52 to 68	4D to 6U	.27	239	$1\frac{1}{4}$, $1\frac{3}{4}$	1
Modification 6; tail surfaces moved rearward 49.30 in. and ventral-fin area added	Effective	Full right	$\frac{2}{3}$ L	$\frac{2}{3}$ U	$\frac{1}{3}$ A	No spin; imparted rotation damps and model dives					7
		Full right	Full left	Full U	Full A	No spin; imparted rotation damps and model dives					
		Full right	Full left	Full D	Full A	45	2U to 17U	0.29	299	∞	
Modification 7; tail surfaces moved rearward 32.63 in. and ventral-fin area added	Effective	Full right	$\frac{2}{3}$ L	$\frac{2}{3}$ U	$\frac{1}{3}$ A	32 to 41	2U to 11U	.24	310	1, $1\frac{1}{4}$	8
		Full right	Full left	Full U	N	35	5U	.22	337	$\frac{3}{4}$, $\frac{1}{2}$	
		Full right	Full left	N	Full A	39 to 52	6U to 17U	.27	284	$1\frac{1}{4}$, 2	
Modification 8; tail surfaces moved rearward 17.40 in. and ventral-fin area added	Effective	Full right	$\frac{2}{3}$ L	$\frac{2}{3}$ U	$\frac{1}{3}$ A	36 to 46	3U to 11U	.25	298	$1\frac{1}{2}$, 2	9
		Full right	Full left	Full U	N	29 to 40	3U	.23	336	$\frac{1}{2}$, $\frac{3}{4}$	

[a]U denoted inner wing up and D denotes inner wing down

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Notation:
- U Up
- D Down
- N Neutral
- L Left
- A Against

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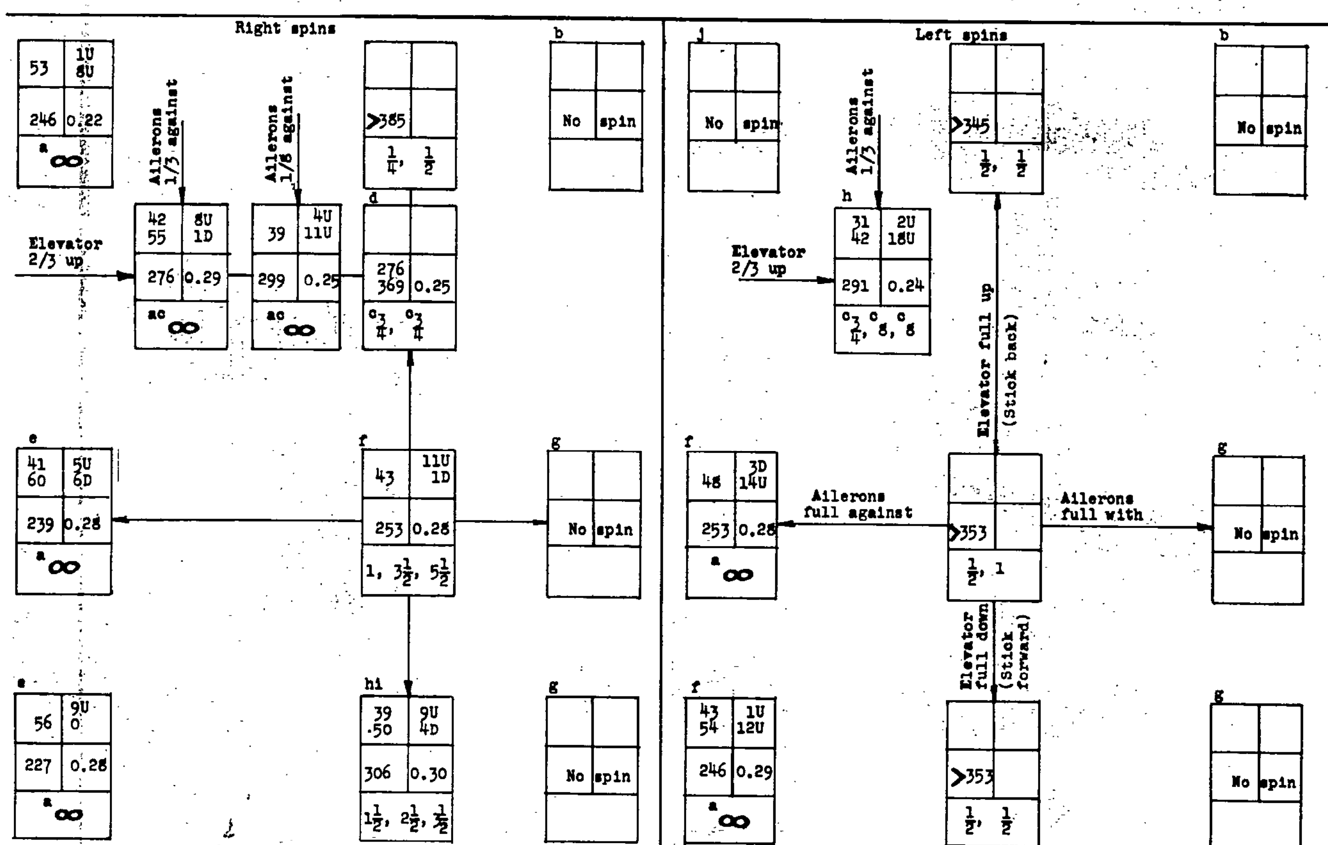
CHART 1.- SPIN AND RECOVERY CHARACTERISTICS OF MODEL WITH 6° WING INCIDENCE

[Normal loading (point 1 on table III and figure 5); landing gear and flaps retracted; cockpit closed; recovery attempted from, and steady-spin data presented for, rudder-with spins); recovery by full rudder reversal unless otherwise indicated; erect spins]



[a]∞ means model required more than 10 turns for recovery.
[b]Goes into a steep aileron roll.
[c]Rudder reversed from full with to 2/3 against the spin for recovery.
[d]Oscillates in pitch.
[e]A spin oscillatory in roll and yaw also obtained.
[f]A "No spin" condition also obtained.
[g]Goes into a steep, tight spiral.
[h]Wanders.
[i]Steeper spin also obtained.
[j]After launching, model becomes increasingly oscillatory in roll and yaw and then goes into a right roll.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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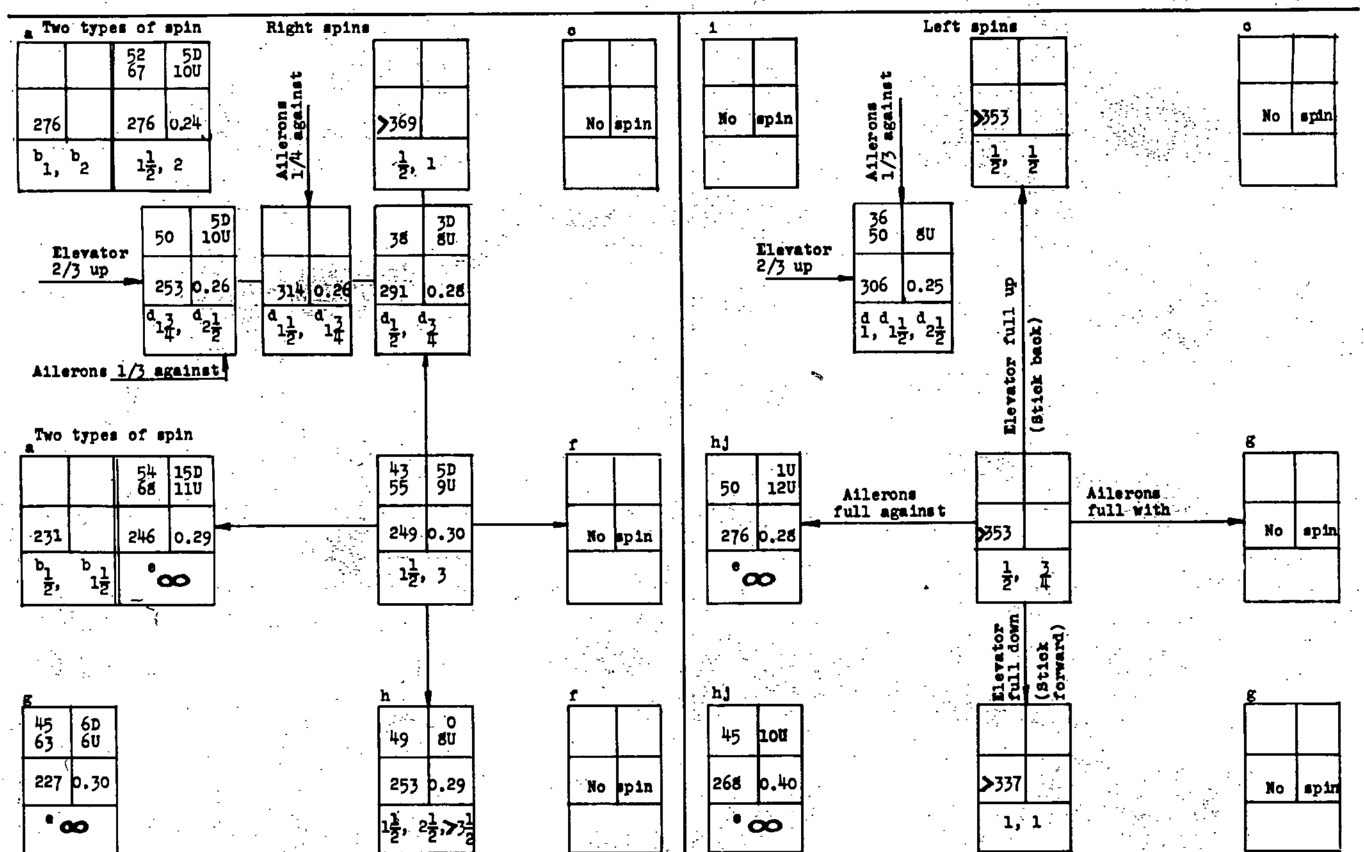
CHART 2.- SPIN AND RECOVERY CHARACTERISTICS OF MODEL WITH 0° WING INCIDENCE

[Normal loading (point 1 on table III and figure 5); landing gear and flaps retracted; cockpit closed; recovery attempted from, and steady-spin data presented for, rudder-with spins; recovery by full rudder reversal unless otherwise indicated; erect spins]



[a]Oscillatory in roll and yaw and wanders.
[b]For recovery, model either goes into a left roll or dives, depending on attitude of model when rudder reversed.
[c]Goes into a steep aileron roll.
[d]Rudder reversed from full with to 2/3 against the spin for recovery.
[e]∞ means model required more than 10 turns for recovery.
[f]Goes into a steep tight spiral.
[g]A spin oscillatory in roll and yaw also obtained.
[h]Wanders.
[i]After launching, model becomes increasingly oscillatory in roll and yaw and then goes into a right roll.
[j]A "No spin" condition also obtained.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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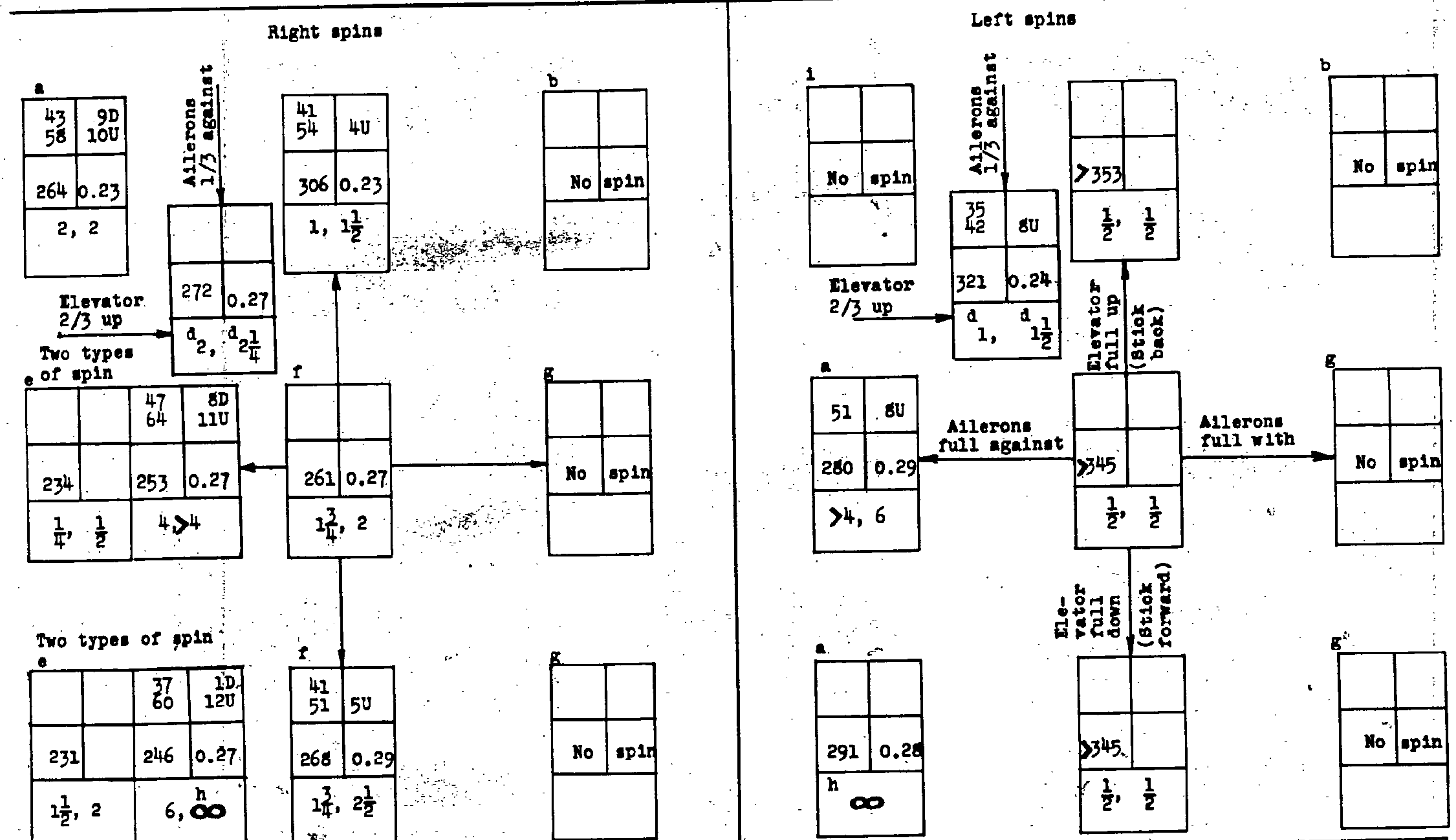
CHART 3.- SPIN AND RECOVERY CHARACTERISTICS OF MODEL WITH -2° WING INCIDENCE

[Normal loading (point 1 on table III and figure 5); landing gear and flaps retracted; cockpit closed; recovery attempted from, and steady-spin data presented for, rudder-with spins; recovery by full rudder reversal unless otherwise indicated; erect spins]



[a]A "No spin" condition also obtained.
[b]Goes into a steep aileron roll.
[c]Oscillates in pitch.
[d]Recovery attempted by reversing the rudder from full with to 2/3 against the spin.
[e]Oscillates in roll and yaw and wanders.
[f]Wanders.
[g]Goes into steep, tight spiral.
[h]∞ means model required more than 10 turns for recovery.
[i]After launching, model becomes increasingly oscillatory in roll and yaw and then goes into a right roll.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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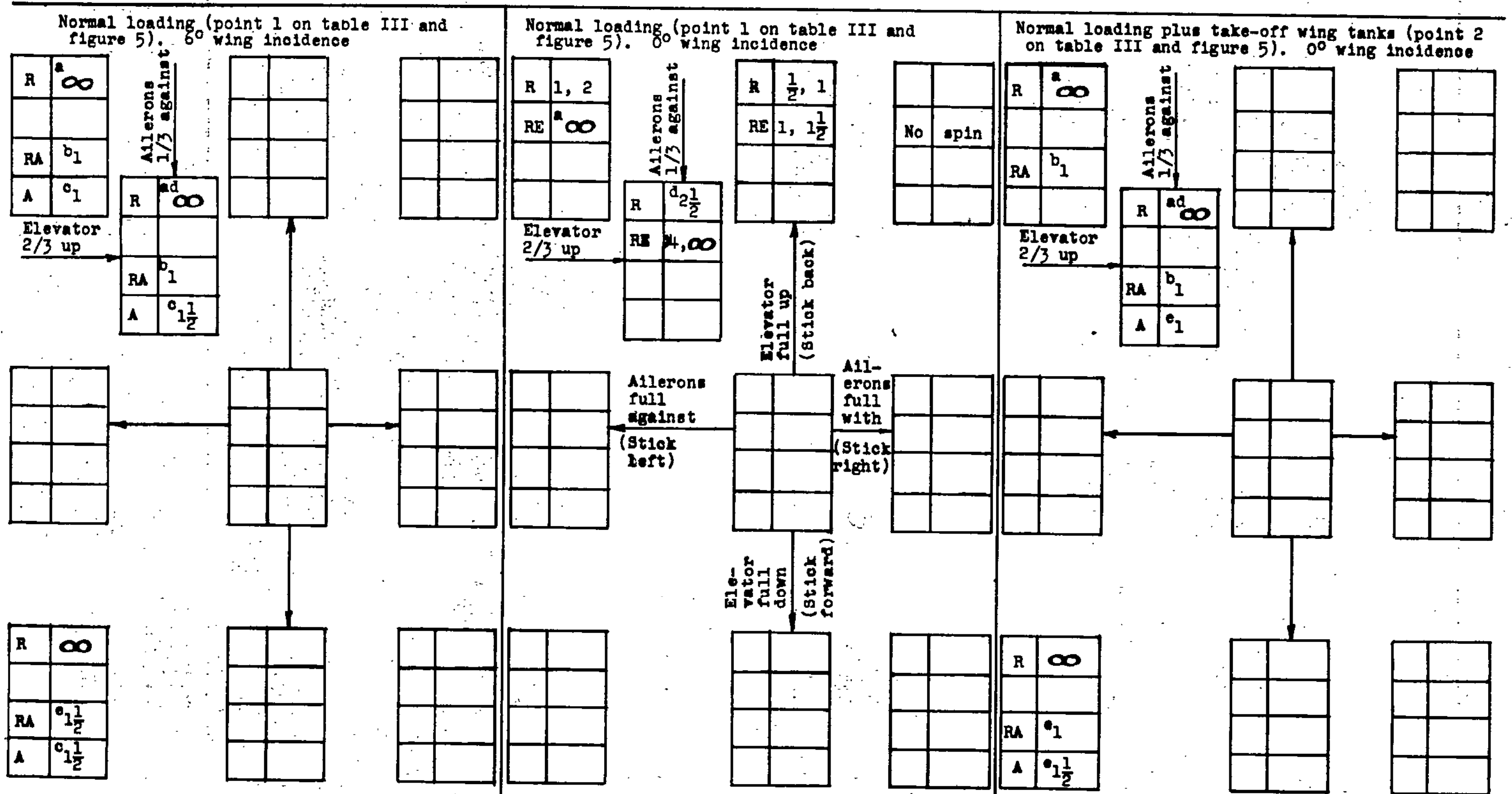
[redacted]

CHART 4.- EFFECT OF VARIOUS CONTROL MOVEMENTS ON THE SPIN-RECOVERY CHARACTERISTICS OF THE MODEL

[Loading and wing incidence as indicated; landing gear and flaps retracted; cockpit closed; recoveries attempted from rudder-full-with spins; right erect spins]



[a] ∞ means model required more than 10 turns for recovery.
[b] Goes into a steep inverted attitude aileron roll.
[c] Goes into a spiral.
[d] Rudder reversed from full with to 2/3 against the spin.
[e] Goes into a steep aileron roll.

Key

Turns for recovery by:	
R	Reversal of rudder
RE	Simultaneous reversal of rudder and elevator
RA	Simultaneous reversal of rudder and movement of ailerons to full with the spin
A	Movement of ailerons to full with the spin

[redacted]

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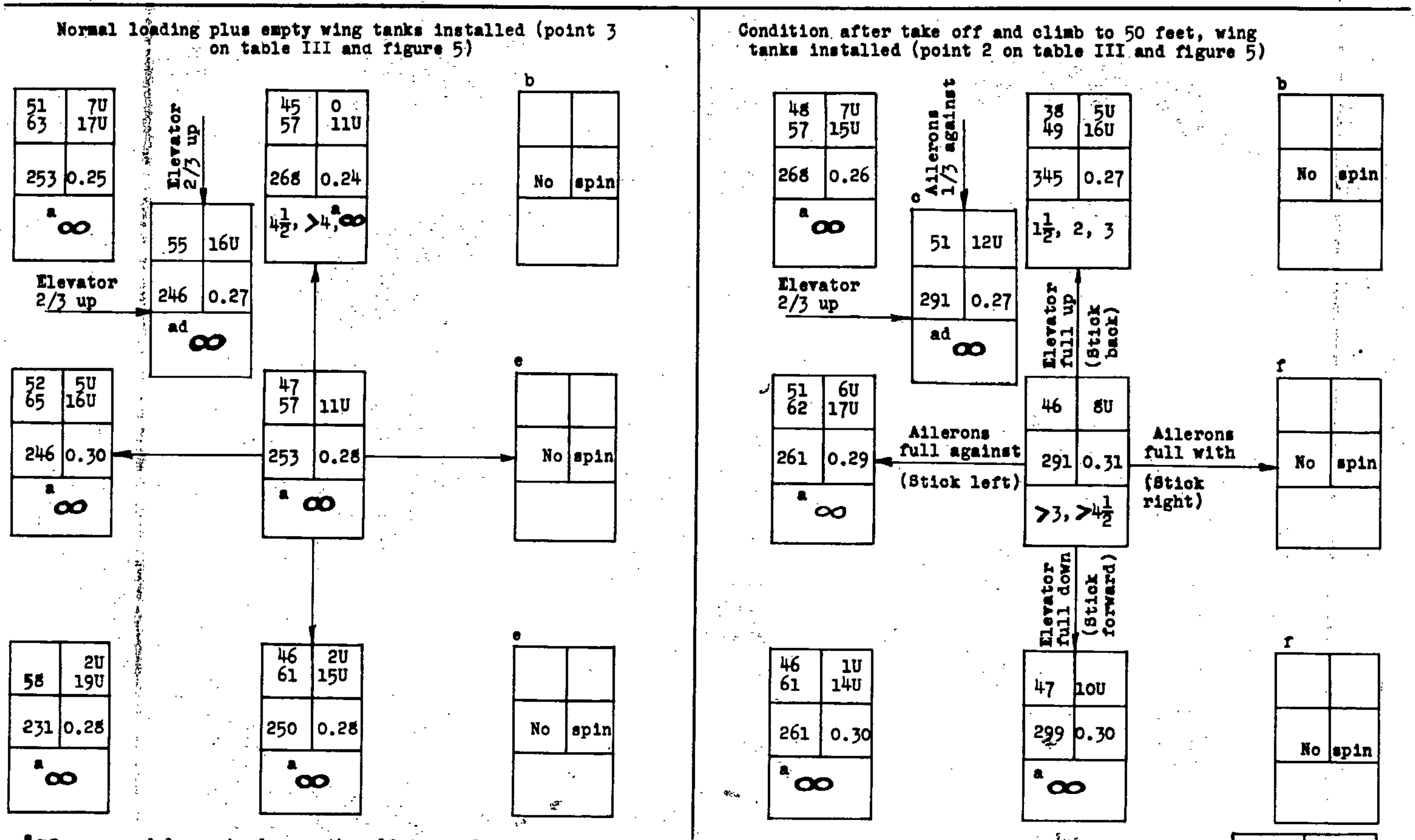
CHART 5.- SPIN AND RECOVERY CHARACTERISTICS OF MODEL WITH WING TANKS INSTALLED AND 0° WING INCIDENCE

[Loading as indicated; flaps and landing gear retracted; cockpit closed; recovery attempted from, and steady-spin data presented for, rudder-with spins; recovery by full rudder reversal unless otherwise indicated; right erect spins]



a∞ means model required more than 10 turns for recovery.
b Goes into a glide or dive.
c Results of left spins similar.
d Rudder reversed from full with to 2/3 against the spin.
e Goes into a steep aileron roll.
f Goes into a steep, tight spiral.

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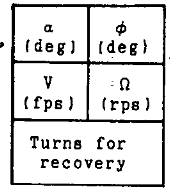
Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down



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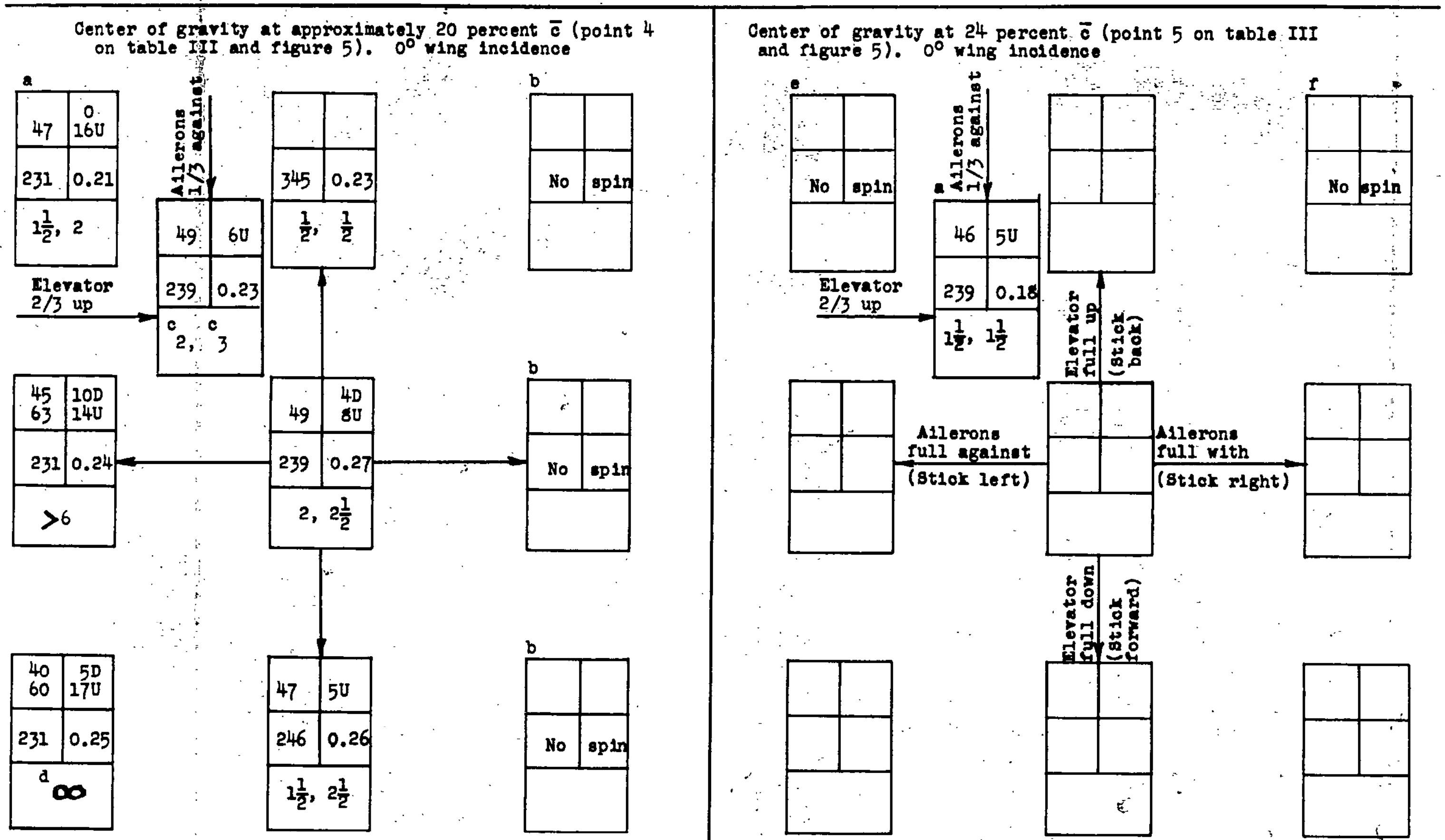
[redacted]

CHART 6.- EFFECT ON MODEL SPIN AND RECOVERY CHARACTERISTICS OF MOVING THE CENTER OF GRAVITY REARWARD

[Loading as indicated; landing gear and flaps retracted; cockpit closed; recoveries attempted from, and steady-spin data presented for, rudder full-with spins; right erect spin]



[a]A "No spin" condition also obtained.
[b]Goes into a steep tight spiral.
[c]Rudder reversed from full with to 2/3 against the spin.
[d]∞ means model required more than 10 turns for recovery.
[e]After launching, model becomes increasingly oscillatory in roll and yaw and then goes into a left roll.
[f]Goes into a glide.

Model values converted to corresponding full-scale values.
U inner wing up
D inner wing down

α (deg)	φ (deg)
V (fps)	Ω (rps)
Turns for recovery	

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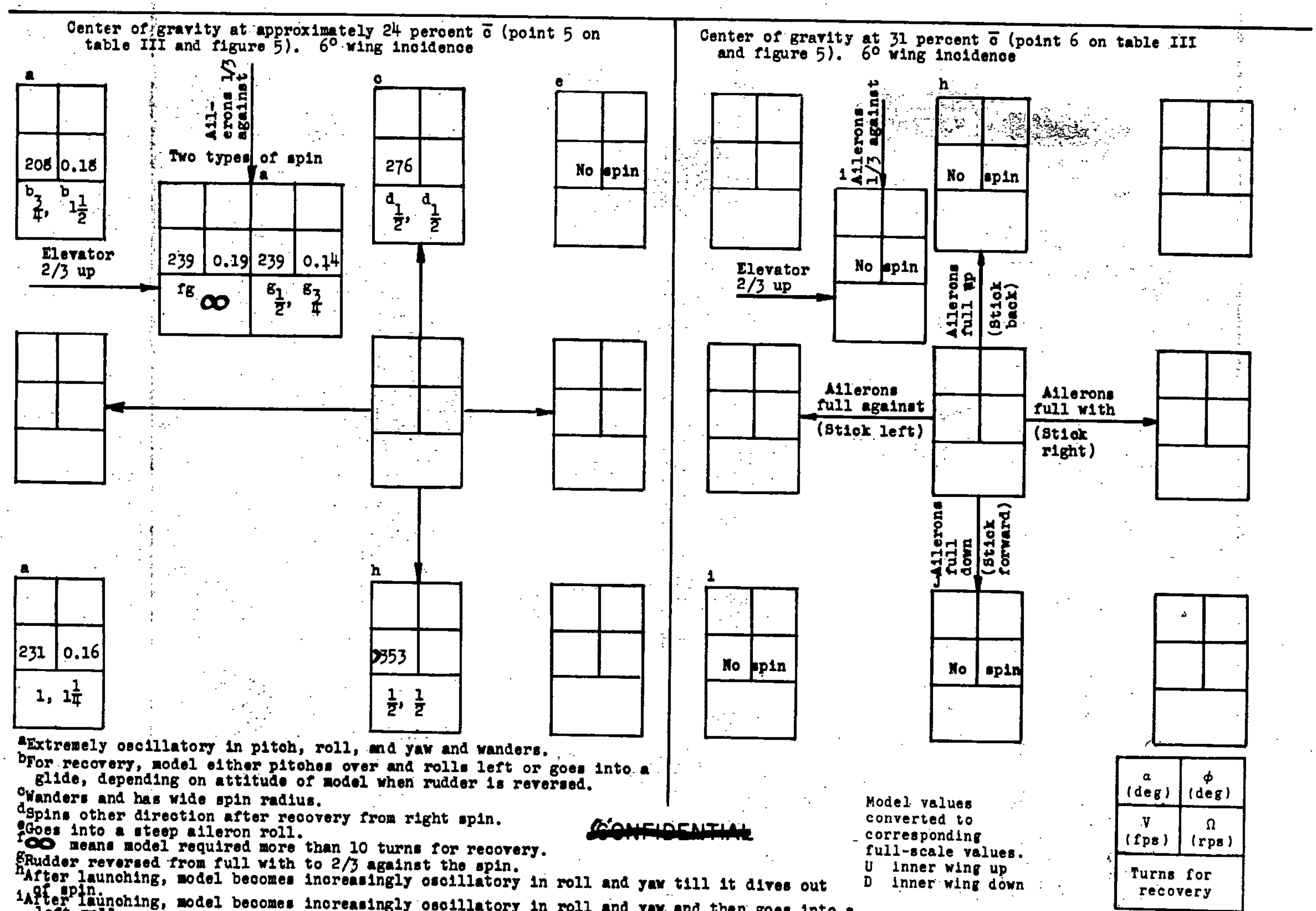
CHART 6.- EFFECT ON MODEL SPIN AND RECOVERY CHARACTERISTICS OF MOVING THE CENTER OF GRAVITY REARWARD (CONCLUDED)



[a]Extremely oscillatory in pitch, roll, and yaw and wanders.
[b]For recovery, model either pitches over and rolls left or goes into a glide, depending on attitude of model when rudder is reversed.
[c]Wanders and has wide spin radius.
[d]Spins other direction after recovery from right spin.
[e]Goes into a steep aileron roll.
[f]∞ means model required more than 10 turns for recovery.
[g]Rudder reversed from full with to 2/3 against the spin.
[h]After launching, model becomes increasingly oscillatory in roll and yaw till it dives out of spin.
[i]After launching, model becomes increasingly oscillatory in roll and yaw and then goes into a left roll.
[j]Goes into a dive.

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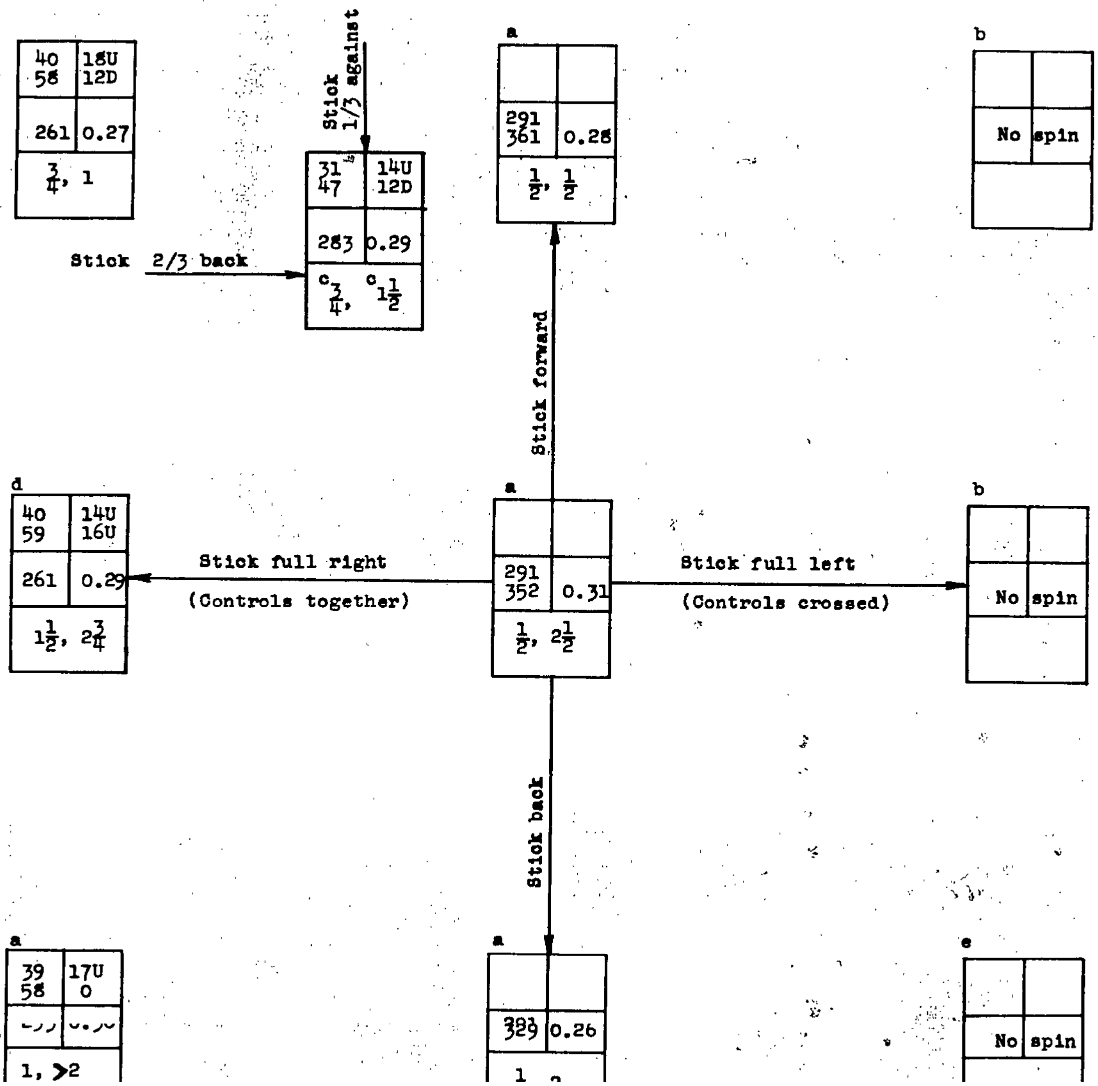
CHART 7.- INVERTED SPIN CHARACTERISTICS OF MODEL WITH 0° WING INCIDENCE

[Normal loading (point 1 on table III and figure 5); flaps and landing gear retracted; cockpit closed; recovery attempted from, and steady-spin data presented for, rudder full-with spins; recovery by full rudder reversal unless otherwise indicated; spins to pilot's right]



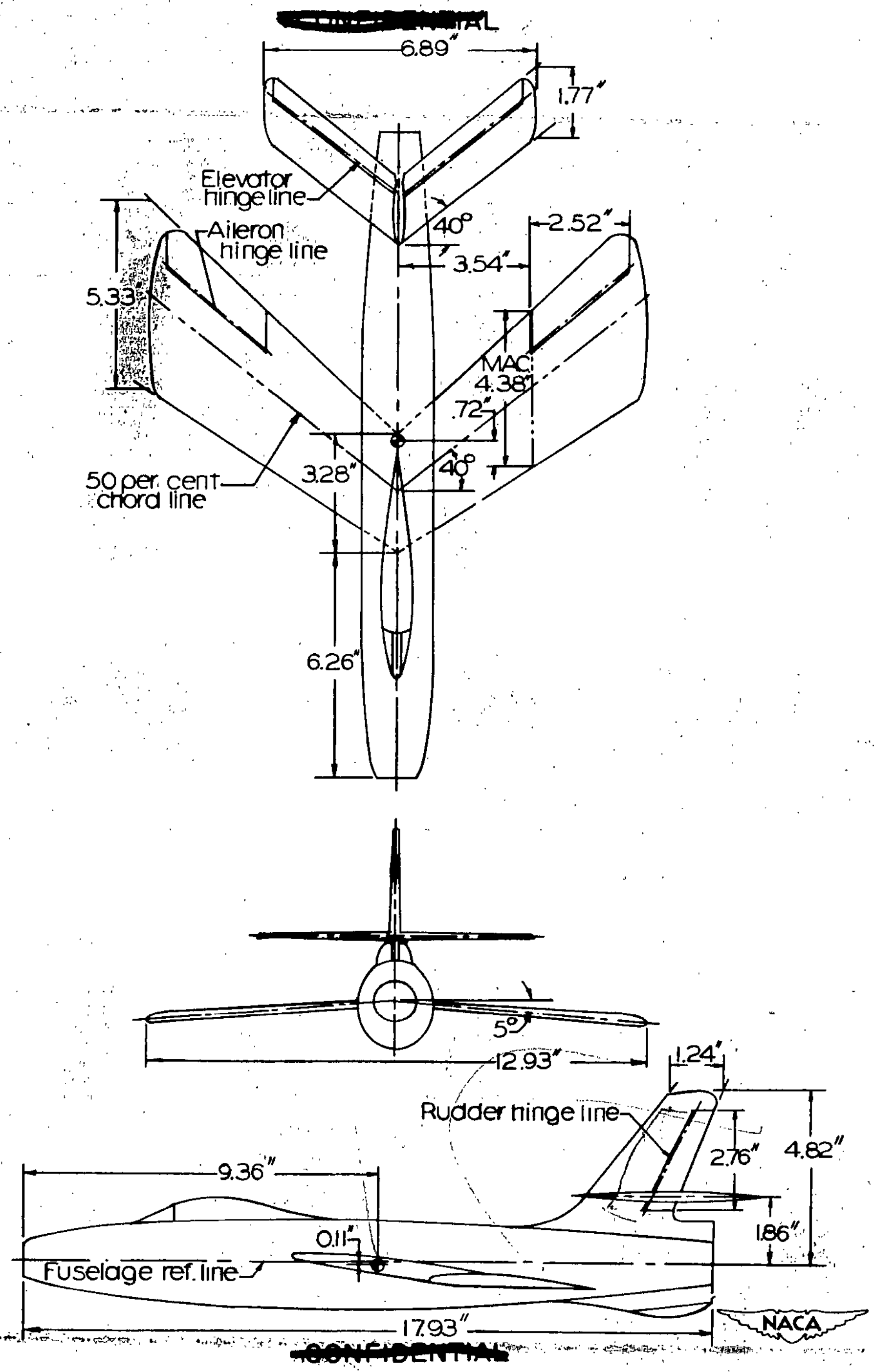


Figure 1.– Three–view drawing of the $\frac{1}{29}$–scale model of the Republic XF–91 airplane with a conventional tail. Center of gravity at 16.5–percent mean aerodynamic chord.

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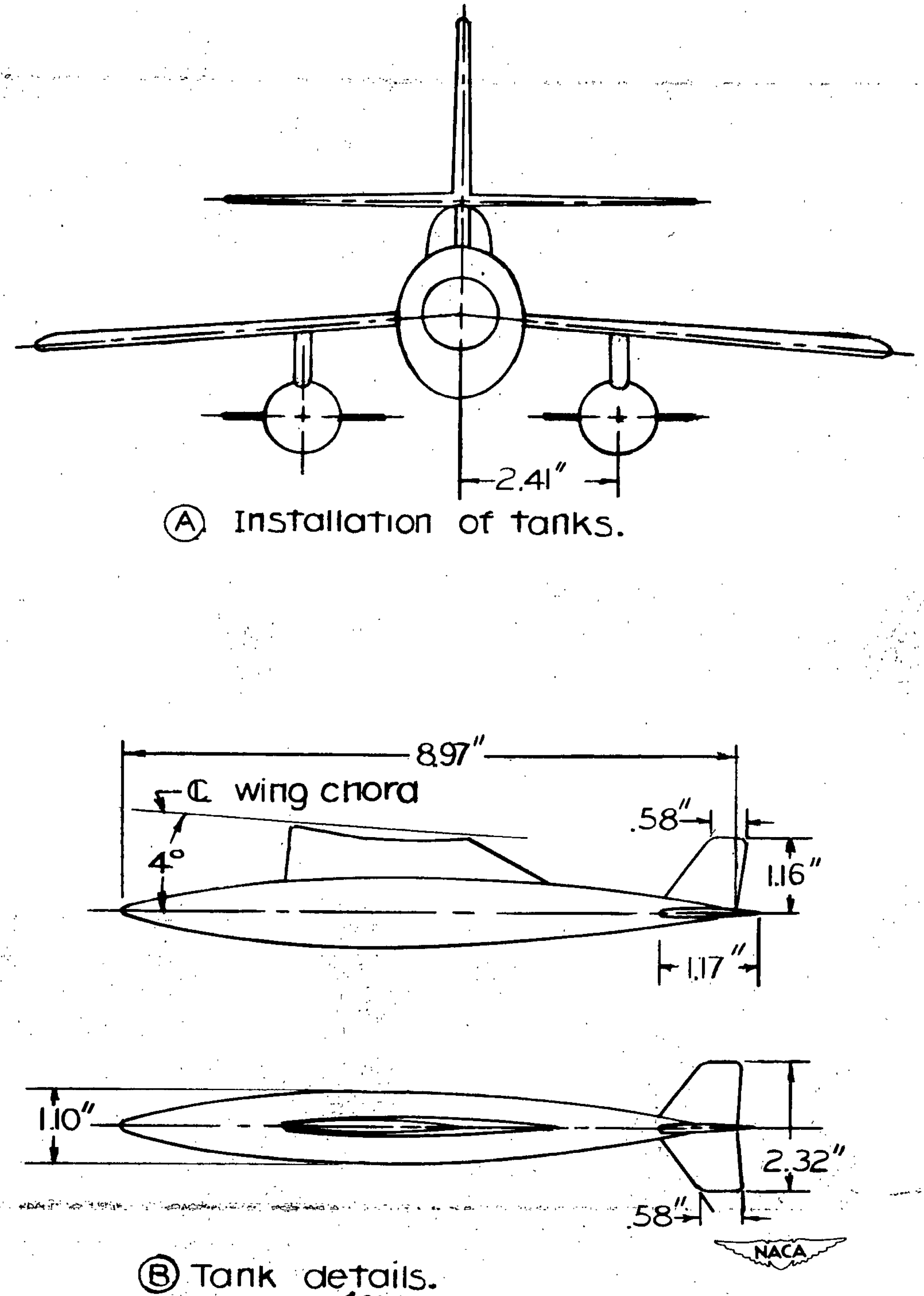

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Figure 2.- External fuel tanks and tank installation on model.

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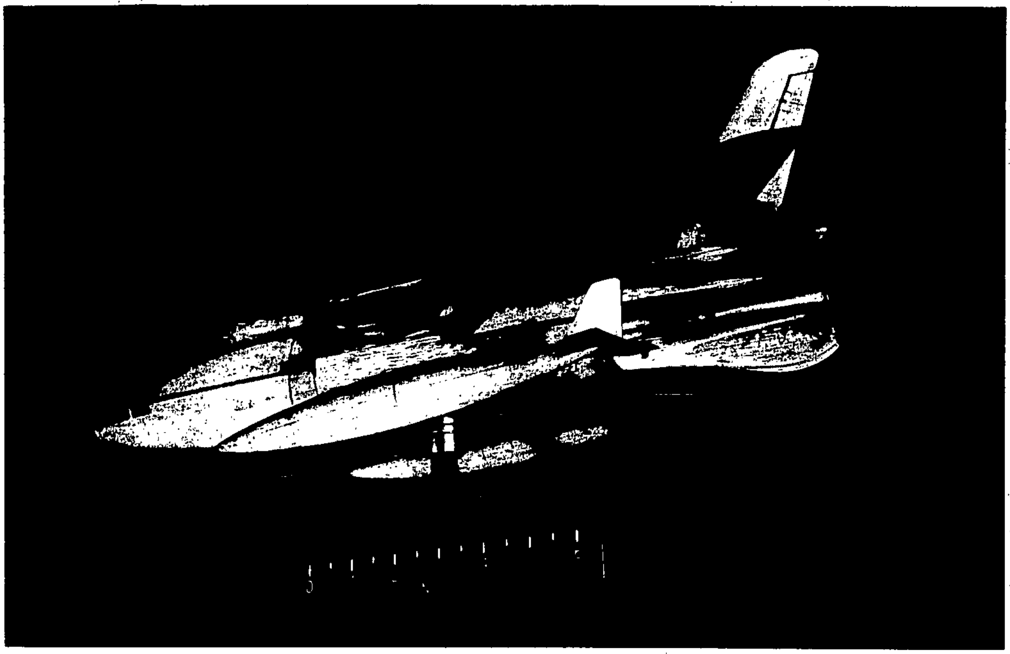
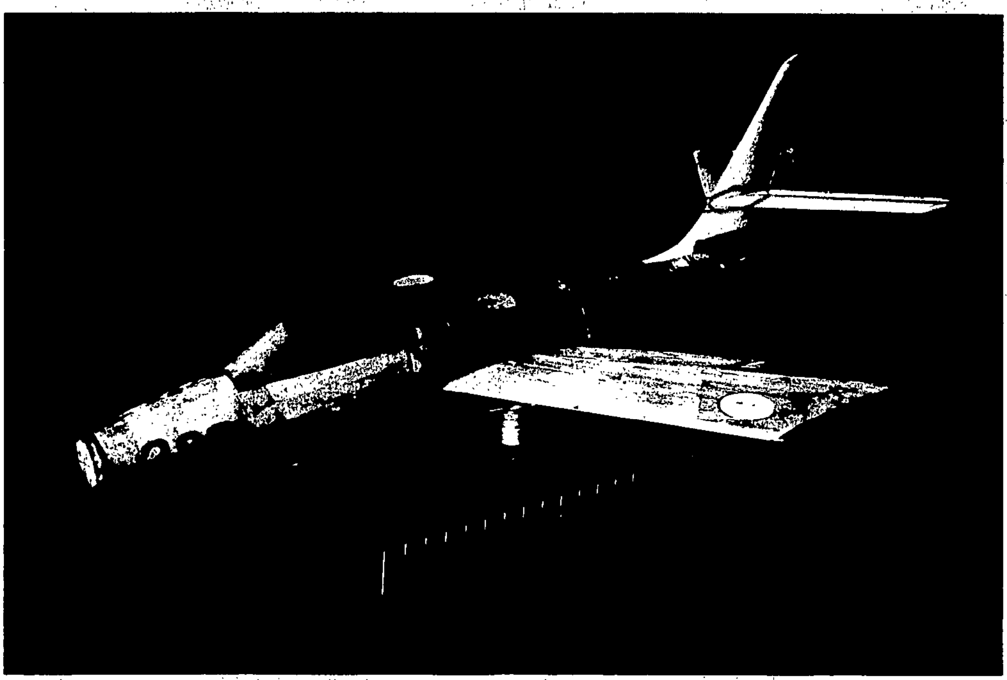


(a) Model with external fuel tanks.



(b) Model without external fuel tanks.

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Figure 3.— Model with and without the external fuel tanks attached.

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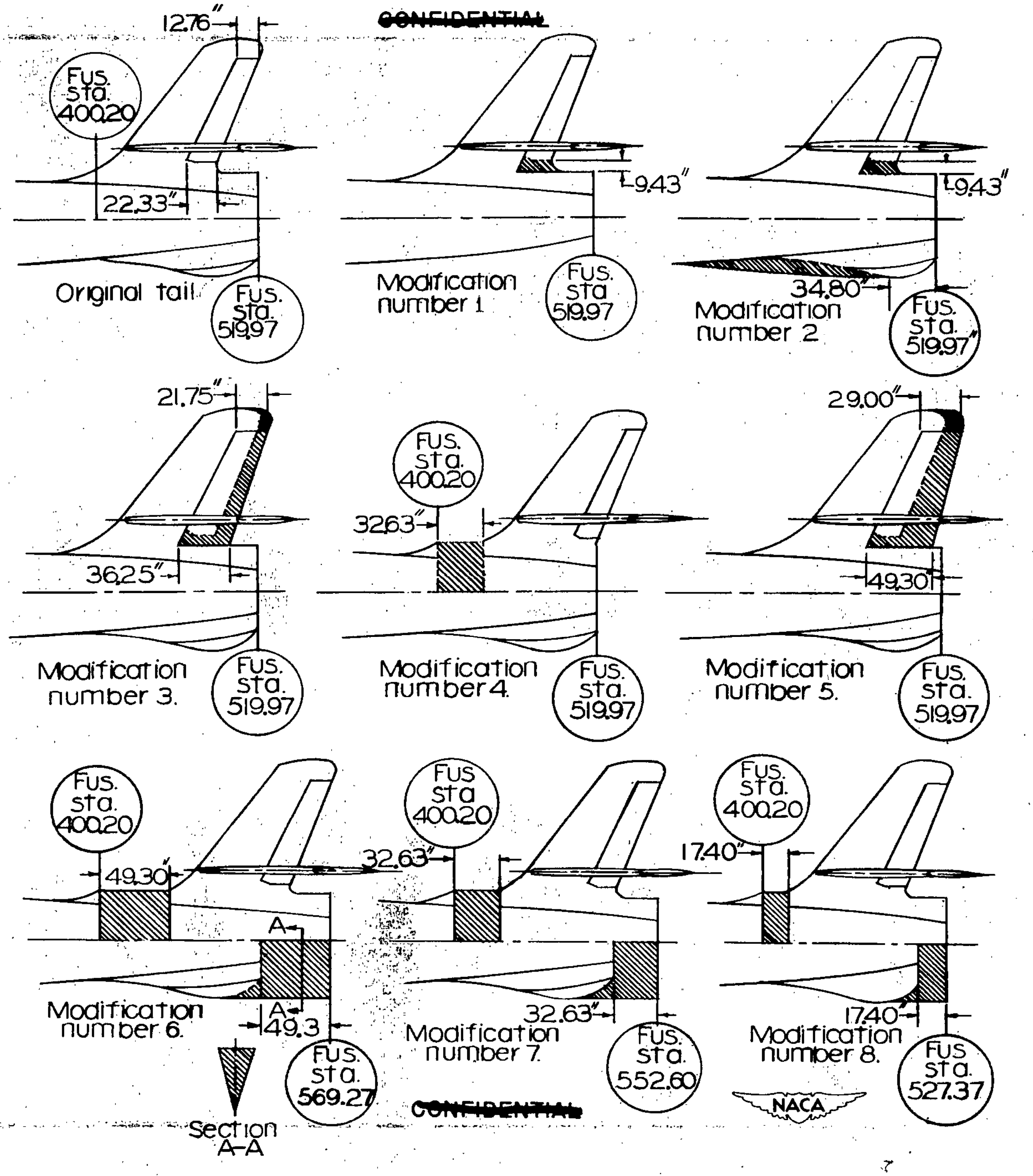

Figure 4.— Comparison of original tail and tail modifications tested on the model. (Dimensions are full scale).

[redacted]

Figure 5.– Model spinning in Langley 20–foot free–spinning tunnel. External fuel tanks installed on model.

[redacted]

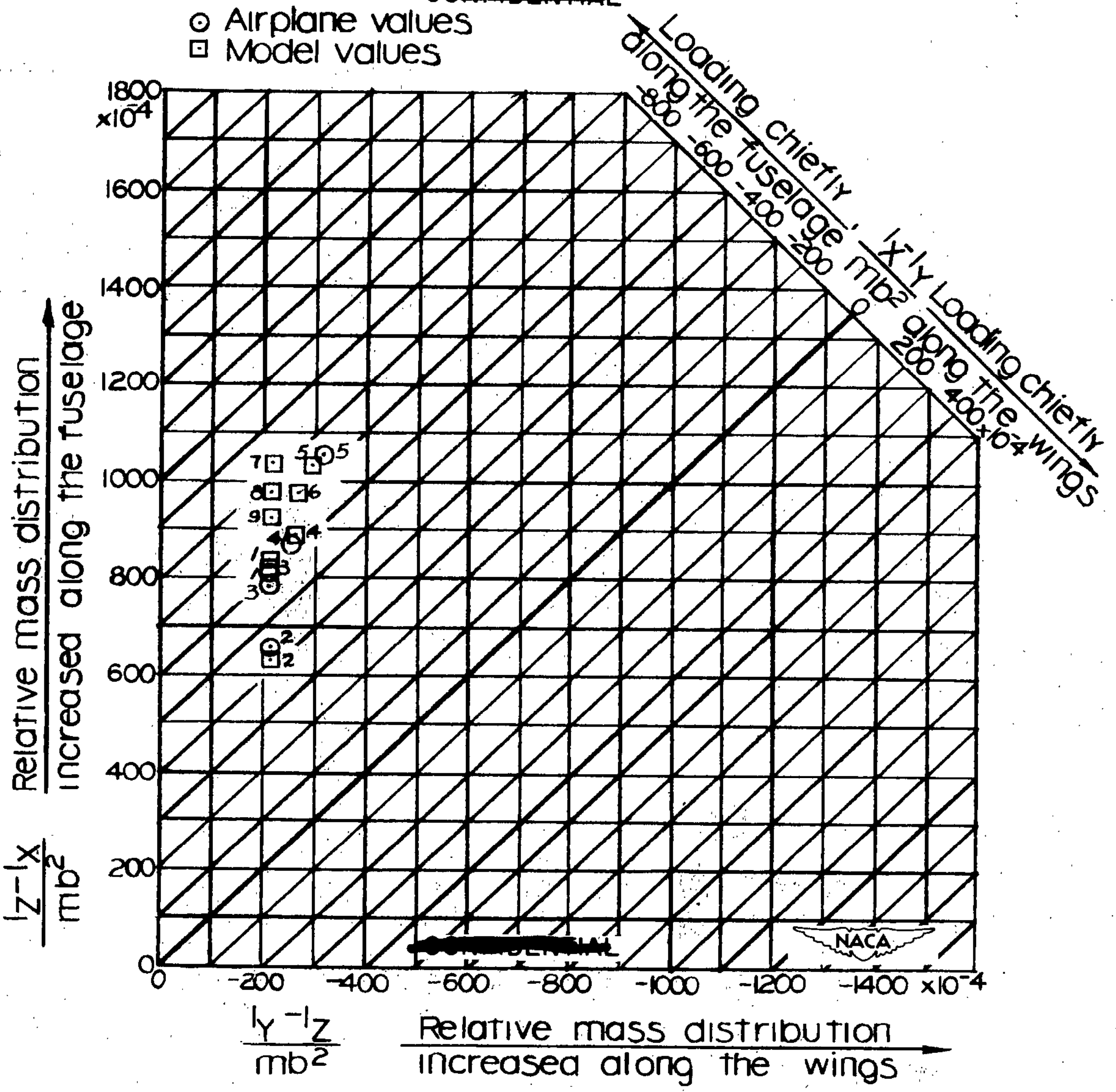

Figure 6.– Mass parameters for loadings possible on the XF-91 airplane and for loadings tested on the model. (Points are for loadings listed in table III.)